## **Contents**

## **Book One of Original Air Force Publication TESTING THE LIFTING BODIES AT EDWARDS**

PDF VERSION FOR ADOBE ACROBAT®	V
SPONSORSHIP	vi
FOREWORD	vi
INTRODUCTION	ix
<u>PREFACE</u>	X
<u>ACKNOWLEDGMENTS</u>	xi
<u>CONTENTS</u>	xiii
ILLUSTRATIONS	xvi
PHOTO OF NASA HANGAR	xix
Chapter 1: Returning From Space	1
1.1 The Capability: Exiting the Atmosphere	1
<u>1.2 The Challenge: Atmospheric Entry</u>	1
<u>1.3 Ballistic Entry</u>	3
<u>1.4 Semi-Ballistic Entry</u>	5
<u>1.5 Lifting Entry</u>	6
<u>1.6 Emergence of the Lifting Body</u>	7
<u>1.7 Glider Landing Techniques</u>	8
Chapter 2:Lifting Entry With Horizontal Landing: The Quest Begins	10
<u>Lifting Bodies: A NASA Perspective</u>	16
Chapter 3: The M2-F1 Program	18
	18
(Continued)	
3.2 Technical and Physical Development	19
<u>3.3 Construction</u>	21
3.4 Flight Testing	23
3.5 Technology Lessons Learned	27
<u>3.6 Test Sites</u>	29
3.7 Current Status of Aircraft	29

Chapter 4: The M2-F2 and M2-F3 Program	30
	30
	31
	34
	40
	48
	52
	56
	59
	60
Chapter 5: The HL-10 Program	61
5.1 Theoretical Development	61
5.2 Technical and Physical Development	62
<u>5.3 Construction</u>	64
5.4 Flight Testing	65
5.5 Technology Lessons Learned	71
<u>5.6 Test Sites</u>	73
<u>5.7 Current Status of Aircraft</u>	73
Chapter 6: The X-24A Program	74
6.1 Theoretical Development	75
6.2 Technical and Physical Development	75
<u>6.3 Construction</u>	80
6.4 Flight Testing	85
6.5 Technology Lessons Learned	90
<u>6.6 Test Sites</u>	95
<u>6.7 Current Status of Aircraft</u>	95
Chapter 7: The X-24B Program	97
	98
	100
<u>7.3 Construction</u>	101
<u>7.4 Flight Testing</u>	105
<u>7.5 Technology Lessons Learned</u>	114
<u>7.6 Test Sites</u>	116
	116
Chapter 8: Epilogue	117

APPENDICES:	
Appendix A: The X-20 "Dyna Soar" Program	123
<u>1.0 Basic Concept and Design Evolution</u>	123
2.0 The X-20 Glider	130
3.0 Configuration Reassessment (Phase Alpha)	136
4.0 Program Cancellation	136
Appendix B: Pilot Comments	142
Appendix C: Lifting Body Flight Logs	160
<u>Part One: Light Weight; M2-F1</u>	161
Part Two: Heavy Weights	164
Appendix D: AFFTC/NASA Memorandum of Understanding	170
Appendix E: Lifting Body Personnel	174
Glossary	179
Source Essay and Literature of the Field	184
About the Author	198

## **Illustrations**

All photos and old artwork images were scanned originally at 300 dpi and in "True Color or 256 gray scale as appropriate. All images were processed with DEBABELIZER PRO at 75% on the "quality" scale to reduce file sizes.

For 1280 X 1024 pixel size images from the NASA Dryden photo server, go to: <a href="http://www.dfrc.nasa.gov/gallery/photo/index.html">http://www.dfrc.nasa.gov/gallery/photo/index.html</a>

There, is an index at that site to retrieve the larger image files for images listed on this table.

Figure # and Title	Page No.	NASA Photo ECN#
Figure 1-1: Entry Angle	2	New
Figure 1-2: Ballistic Coefficient	3	New
Figure 1-3: Ballistic Entry	4	New
Figure 1-4: Semi-Ballistic Entry	5	New
Figure 1-5: Lifting Entry	6	New
Figure 1-6: Lifting Body Entry	8	New
Figure 2-1: Entry-Related Testing 1957-1982	11	New
Figure 2-2: Dyna Soar Glider on Titan III Booster	13	?
Figure 3-1: Evolution of M2 Lifting Body Design	18	?
Figure 3-2: Three-View Drawing, M2-F1	19	?
Figure 3-3: Internal Structure of the M2-F1	20	E-10756
Figure 3-4: M2-F1 in Ames 40 X 80 Wind Tunnel	21	A-33718
Figure 3-5: Pontiac Convertible Tow Vehicle	22	ED9643663-1
Figure 3-6: M2-F1 Low Speed Car Tow	24	E-9829
Figure 3-7: M2-F1 Air Tow Behind C-47	24	E-10962
Figure 3-8: M2-F1 in Free Flight using "Instant L/D Rocket"	25	?
Figure 3-9: M2-F1 Trimmed Lift/Drag Ratio	28	?
Figure 4-1: Comparison of M2-F1 and M2-F2 Configurations	31	?
Figure 4-2: Three-View Drawing of M2-F2	32	?
Figure 4-3: M2-F2 Cutaway Drawing	35	E-12972
Figure 4-4: XLR-11 Rocket Engine	36	E-23356
Figure 4-5: Air Force Rocket Engine Test Facility (RETF)	37	?
Figure 4-6: M2-F2 and HL-10 Manufacturing Schedule	38	
Figure 4-7: M2-F1 and M2-F2 Lifting Bodies	38	1107 (E-14339)

Figure # and Title	Page No.	NASA Photo ECN #
Figure 4-8: M2-F2 in Full Scale Wind Tunnel)	39	847 (E-13742)
Figure 4-9: Air Force Hybrid Simulation of M2-F2	41	?
Figure 4-10: Typical Lifting Body Ground Track	43	?
Figure 4-11: Typical Lifting Body Approach, Flare and Landing	43	?
Figure 4-12: NASA FRC Circa 1966	44	646
Figure 4-13: Mating of M2-F2 with B-52 at NASA Hanger	45	E-13865
Figure 4-14: M2-F2 in Captive Flight	46	1438
Figure 4-15: M2-F2 Lifting Body with F-104 Chase	47	1701
Figure 4-16: M2-F2 After Crash on Lakebed	48	E-16731
Figure 4-17: Variation of M2-F2 Roll Characteristics with Interconnect Ratio	49	?
Figure 4-18: M2-F3 in Flight	50	2924
Figure 4-19: M2-F3 Powered Flight	52	3272
Figure 4-20: Location of Lifting Body Facilities at Edwards	53	?
Figure 4-21: NASA Mission Control Room	54	E66-15774
Figure 4-22: Dry Lakebeds Near Edwards AFB Used for Lifting Body Operations	55	?
Figure 5-1: Three-View Drawing of HL-10	62	?
Figure 5-2: HL-10 Control Surface Configurations	63 64	1463 1462
Figure 5-3: NASA HL-10 Simulator	66	E-18900
Figure 5-4: HL-10 Glide Flight	67	63-187 69-2346 (E-21089)
Figure 5-5: Inward-Cambered Glove Modification to HL-10 Fins	68	?
Figure 5-6: HL-10 Landing	70	2367
Figure 6-1: Three-View Drawing of X-24A	77	?
Figure 6-2: X-24A Control Surface Configurations	78 78	E-23373 E-23377
Figure 6-3: X-24A Cutaway Drawing	81	?
Figure 6-4: X-24A Propulsion System Test Stand	82	?
Figure 6-5: X-24A in Full Scale Tunnel with Simulated Ablative Coating	83	1926 (E-18533)
Figure 6-6: X-24A Iyy Inertia Test Setup	84	?
Figure 6-7: X-24A Simulator Cockpit	85	?
Figure 6-8: X-24A Glide Flight	87	?
Figure 6-9: X-24A Powered Flight	89	2511 (E-21733)
Figure 6-10: X-24A In-Flight Jettison	92	?
Figure 6-11: Lifting Bodies Displayed in AF Museum, WPAFB	96	?
Figure 7-1: X-24B Glove Modification to X-24A	99	?
Figure 7-2: Three-View Drawing of X-24B	99	?
Figure 7-3: X-24B Upper Body Shape	100	?
Figure 7-4: X-24A Conversion to X-24B	102	?

Figure # and Title	Page No.	NASA Photo ECN #
Figure 7-5: X-24B Landing Gear Drop Test	104	E-26140
Figure 7-6: X-24B High Speed Taxi Test using XLR-11 Rocket Engine	105	?
Figure 7-7: X-24B Glide Flight (Touchdown)	107	4914
Figure 7-8: X-24B Fuel Jettison Modification	108	?
Figure 7-9: X-24B Powered Flight	109	EC75-4638
Figure 7-10: X-24B Runway Landing	111	?
Figure 7-11: Test Pilots Who Flew the X-24B	113	4968
Figure 8-1: L/D Comparisons, Gear Up	119	?
Figure 8-2: L/D Comparisons, Gear Down	119	?
Figure 8-3: Orbital Entry Footprints for Lifting Bodies and Other Vehicles	121	?
Figure A-1: Entry-Related Testing 1957-1982	123	New
Figure A-2: Dyna Soar	125	?
Figure A-3: Planned Dyna Soar Sub-Orbital Tests	127	?
Figure A-4: Dyna Soar Glider on Titan III Booster	129	?
Figure A-5: Once-Around to Edwards	130	?
Figure A-6: Dyna Soar, X-20 Glider	131	?
Figure A-7: X-20 L/D vs. Angle of Attack	132	?
Figure A-8: Energy Management Overlay, X-20	132	?
Figure A-9: Flight Integrator Overlay, X-20	134	?
Figure A-10: Assigned Pilots for the X-20 Dyna Soar	139	?
Figure A-11: ASSET Vehicle Configuration	140	?
Miscellaneous Images With No Figure Numbers Figure # and Title	Page No.	NASA Photo ECN #
McCall Mural	i	EC 77 8474
Footprint Cover	ii	New
Frontispiece	iv	New
NASA Hangar with X-15s and Lifting Bodies Research Aircraft, 1966)	xix	1.0
HL-10 on Pedestal	61	
M2-F3 Head-on Photo	51	EC70 2454
HL-10/ Bill Dana With B52 Fly-over	70	2203
X-24B & 3 Chase	112	EC73 4895
X-24B, M2-F3, and HL-10 Lifting Bodies	10 145	2357
M2-F2 and F-104 Chase	30	?
M2-F1 Glide Flight	17	EC 64 406
M2-F1 Under Tow	17	EC 63 299
Bruce Peterson and the M2-F2	144	?
X-24A on B52 Pylon	74	?
X-24B Glide Flight	97	EC 75 4642